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ECLIPSE BURNS IN HUMANS AND LABORATORY THRESHOLD MEASUREMENTS IN RABBITS

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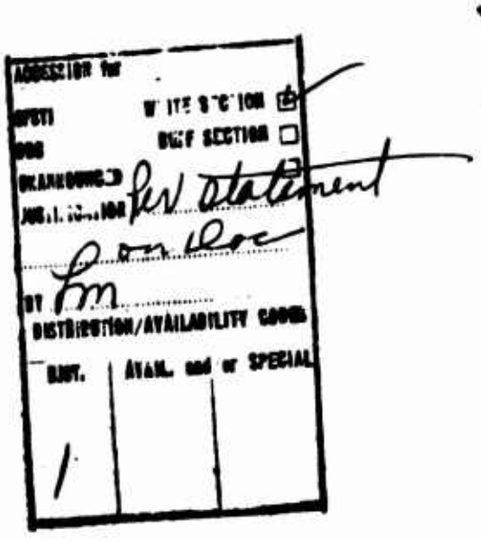

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FOREWORD

This report was prepared in the Air Force Office of Scientific Research, Washington, D. C., and the Ophthalmology Branch, USAF School of Aerospace Medicine, under task No. 630103 and project No. 5710. The work was accomplished in July 1965.

This report has been reviewed and is approved.

Harold V. Ellingson

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Commander

ABSTRACT

The radiant energy incident on the retina of a human viewing the noon-day sun is calculated as 4.25 cal./cm.^{2}-sec. with an image diameter of 0.16 mm., assuming an atmospheric transmission of 85% and a pupil diameter of 2.5 mm. The retinal irradiance under the limiting conditions of 100% atmospheric transmission and 6 mm. pupil diameter is shown to be only 29 cal./cm.^{2}-sec. This retinal irradiance is compared to experimentally determined retinal burn thresholds in rabbits. It is concluded that eclipse burns, which are known to occur, would not be predicted on the basis of extrapolated animal data, and that care must be exercised in using existing animal threshold data in predicting chorioretinal damage in humans.

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I. INTRODUCTION

It has been known for many years that damage to the retina can occur as a result of viewing a very intense light, and that this damage could produce a permanent loss of visual acuity. Early evidence of retinal damage produced in this way was observed in individuals who had viewed a solar eclipse with the naked eye or with inadequate eye protection (1). The resulting loss in vision has been called "eclipse blindness," and despite frequent warnings to the public concerning the dangers involved, injuries from viewing eclipses are still being reported (2, 3). One of the most recent studies on eclipse retinitis involved approximately 50 instances which occurred in the Hawaiian Islands during the solar eclipse of 4 February 1962 (4).

II. MECHANISM BY WHICH INJURY IS PRODUCED

The mechanism by which retinal injury is produced has been recognized to be the production of a region of elevated temperature in the retina and its vicinity as a result of the absorption of incident radiant energy—primarily energy in the visible and near infrared. It is apparent that the distribution of temperature will depend upon the amount and spatial distribution of absorbing material—mainly the pigmented epithelium. When the temperatures generated exceed the tolerances of the biologic systems involved, damage (chorioretinal burns) and associated permanent loss of visual function result.

Since damage appears to be a direct consequence of the duration, extent, and magnitude of the temperatures produced in the retina and adjacent structures (1, 5), a knowledge of the time history and spatial distribution of the temperature is important to understanding and predicting the results to be expected from an exposure. However, reliable information on actual temperatures generated in the retinal region is essentially nonexistent, and in lieu of such data resultant injury has been related to retinal exposure in terms of three quantities: (1) the total energy per unit area falling on the retina (or the exposure duration), (2) retinal irradiance (energy incident on the retina per unit area per unit time), and (3) the image size (image diameter for a circular image). Intuitively, these quantities should be involved since the temperatures achieved will depend upon the rate of absorption of energy relative to the rate of conduction of energy away from the site at which it is absorbed, and a detailed analysis of the problem (6) demonstrates the dependence of temperature on these three quantities.

III. CALCULATION OF RETINAL EXPOSURE

The retinal exposure resulting from viewing the sun can be calculated with reasonable accuracy if the exposure conditions are known. The effective irradiance on the retina (H_r) from the sun may be written as

$$H_r = a \frac{A_p}{A_i} \bar{T}_c \bar{T}_{at} H_s \text{ (cal./cm.}^2\text{-sec.)} \qquad (1)$$

where:

a = 0.8, that fraction of the total energy emitted by a black body radiating at 5800° K that lies between 350 mμ and 1500 mμ.

A_p = area of pupil in mm.^{2}

A_i = area of image of sun on retina in mm.^{2}

$\overline{T}_e$ = 0.8, average transmission of the clear media of the human eye for the sun spectrum (5)

$\overline{T}_{at}$ = average transmission of the atmosphere between the observer and the sun

H_s = 0.032 cal./cm.^{2}-sec., the irradiance from the sun at the top of the earth's atmosphere

The total radiant exposure (Q_r) in the area of the image is simply

$$Q_r = H_r t \text{ (cal./cm.}^2\text{)} \qquad (2)$$

where t is the duration of the exposure in seconds.

The most favorable condition for producing retinal lesions would be that in which the sun was viewed while it was directly overhead on a clear day. Under the circumstances the atmospheric transmission would be about 85%. Using this value for the atmospheric transmission for one air mass and assuming the effective focal length of the human eye to be 17 mm. (giving a diameter of 0.16 mm. for the sun's image on the retina) H_r becomes

$$H_r = 0.68 d_p^2 \qquad (3)$$

From this expression it is seen that a change in pupil diameter (d_p) can produce a sizable change in the retinal exposure. In bright sunlight the average pupil diameter for humans is between 2 and 3 mm. (7). Under conditions of a solar eclipse, lowered ambient illumination may result in the pupil's dilating to a diameter of 3 to 4 mm. Fixation on the sun, however, will cause pupil contraction and a reasonable choice for the average pupil diameter would seem to be about 2.5 mm.

Using this value in equation 3

$$H_r = 4.25 \text{ cal./cm.}^2\text{-sec.} \qquad (4)$$

over an image having a diameter of 0.16 mm.

IV. COMPARISON WITH EXPERIMENTALLY DETERMINED THRESHOLD EXPOSURES

In 1956-1957, Ham et al. (5) made a systematic investigation of the threshold for minimum observable retinal burns in pigmented rabbits. The burn thresholds determined in that investigation are reproduced in figure 1 along with additional data obtained by the same authors in 1962. For comparison purposes figure 2 shows retinal exposures calculated for humans (at irradiances of 4.25 and 29 cal./cm.^{2}-sec.) along with the threshold curves for 0.18 and 0.24 mm. diameter images (extrapolated linearly). If the sensitivity of the human retina is the same as in the rabbit, as was assumed by Ham in the absence of experimental evidence indicating otherwise and as has been suggested by the absorption measurements of Geeraets (9), an explanation of eclipse burns seems to be in order since it is not evident from these threshold experiments with rabbits that retinal burns would be produced in humans as a result of viewing the sun. At least, this is a tentative conclusion that can be drawn from the observation that the human radiant exposure curves do not intersect the linearly extrapolated burn threshold curves for rabbits corresponding to 0.18 mm. or 0.24 mm. diameter images. From the trend of the experimental observations (fig. 1), it seems even less likely that the exposure curves would intersect the curve anticipated for the 0.16 mm. diameter image of the sun—again under a linear extrapolation.

V. DISCUSSION

The retinal exposure curve corresponding to a retinal irradiance of 29 cal./cm.^{2}-sec. was obtained using more conservative assumptions (an atmospheric transmission of unity and a pupil diameter of 6 mm.) and on the basis described above, even with this irradiance, solar retinal burns in humans would not be predicted.

If the data for these small images are valid, then the only other explanations readily available involve the possibilities that (1) a linear

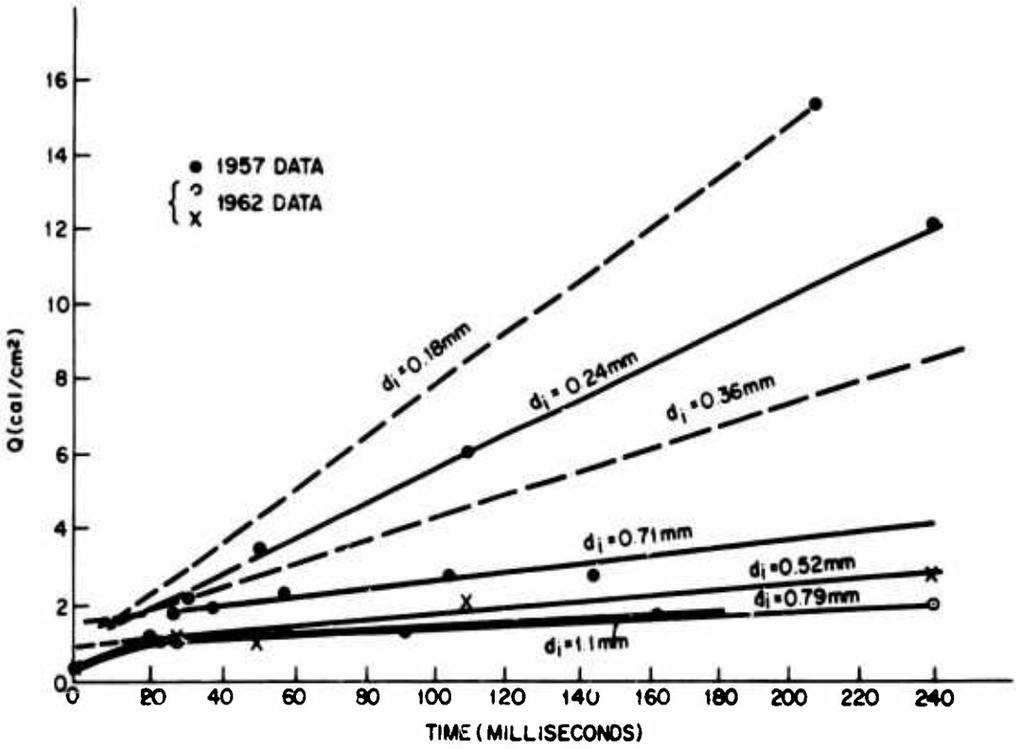

FIGURE 1

Threshold dose versus time for minimal retinal burn in pigmented rabbits at several retinal image diameters. (From Ham et a. (5))

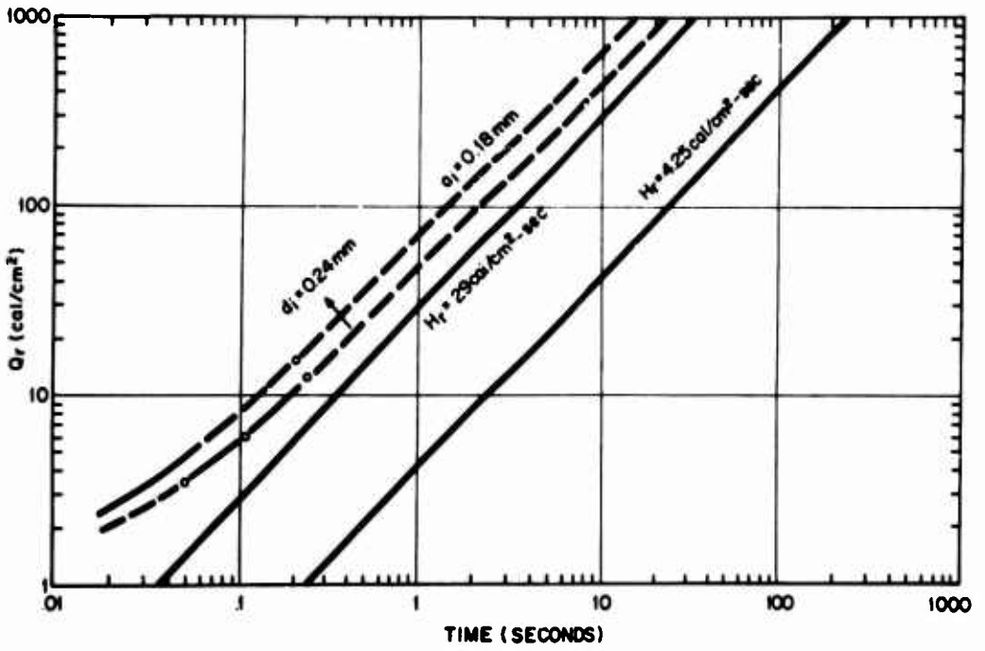

FIGURE 2

Radiant retinal exposure from the sun compared to extrapolated minimal retinal burn thresholds for 0.18 mm. and 0.24 mm. image diameters.

extrapolation of the rabbit threshold data much beyond the range of the measurements may not be appropriate, (2) the human retina may be more sensitive than the rabbit retina—at least in the macular area, or (3) minimum detectable burns in rabbits, as defined by Ham et al. (5), and eclipse burns in humans do not represent equivalent pathologic end points.

If the threshold burns in rabbits are not "equivalent" to eclipse burns in humans, then a simple comparison of irradiation ratio is not particularly significant. What is significant is that, under some circumstances, irradiation rates much lower than those indicated in rabbit thresholds appear to be hazardous to humans. If, as seems to be the case, the protein damage threshold is a function of both time and temperature so that, as the temperature is lowered, the time required to produce irreparable injury increases (8), then injury will result only from an exposure that exceeds the time-temperature threshold for damage. It may be that, at the relatively low irradiance produced by the sun (4.25 cal./cm.^{2}-sec.), and for the small image size (0.16 mm. diameter), a relatively lengthy exposure is needed to exceed the time-temperature damage threshold of the retinal processes—perhaps as much as 10 to 30 seconds (10). However, in this connection it should be noted that Ham et al. were unable to produce observable lesions in rabbits with an irradiance of 70 cal. cm.^{2}-sec. at an image diameter of 0.12 mm. with exposures up to 1.14 seconds. Unfortunately, the paucity of data on retinal damage involving images of these small sizes (in humans or animals) makes it difficult to describe the relationship between the irradiance (H_r) and the threshold exposure (Q_r) with any confidence.

VI. CONCLUSIONS

The well-documented history of eclipse burns in humans and the ability to calculate the retinal irradiance for the sun with reasonable accuracy establishes a plausible basis for "cause and effect." However, the lack of experiments or episodes in which complete information is available prohibits an examination of the "cause and effect" relationship with any degree of thoroughness.

From an examination of results obtained by using laboratory animals (rabbits), there seems to be an uncertainty concerning the appropriate interpretation of these experimental results and their extrapolation to humans in connection with the question of eclipse burns. Specifically, it appears that (1) the relationship between eclipse burns and minimum detectable rabbit burns needs to be clarified, (2) the assumption of equal sensitivity between the rabbit and human retina should be demonstrated conclusively before this equivalence is relied upon in predicting chorioretinal burn thresholds for humans, and (3) considerable care should be exercised in extrapolating existing animal threshold burn data beyond the regions in which they were actually obtained.

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